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EXECUTIVE SUMMARY

SEISMIC TESTING OF NATURALLY AGED C&D LCU-13 STATION BATTERY CELLS

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A sample of ten year old lead acid storage batteries from the North Anna Nuclear Power Station (Virginia Electric and Power Company) were tested on a shaker table. The intensity of the shaker tests reached the full capacity of the table. All seven cells tested were able to deliver an acceptable level of power during three hours discharge tests before and after simulated earthquakes on the shaker table. Following the tests, a number of cells were disassembled and examined. Internal components were found to be in good condition.

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To Mr. B.A. Oliver
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SEISMIC TESTING OF NATURALLY AGED C&D LCU-13 STATION BATTERY CELLS

1.0 INTRODUCTION

The large lead-acid storage battery cells that are the subject of this report are used to provide dc power for nuclear power stations during and after an earthquake. It is well known that these cells deteriorate with age and it is normal practice to test them at regular intervals to ensure that they are capable of meeting a specified level of performance. What is not so well understood however, is the effect of age on the mechanical fragility of the cells and whether the cells would be capable of surviving seismic events at the operating basis earthquake (OBE) or safe shutdown earthquake (SSE) levels and to continue to meet the load profile required by the Class 1E system. Because of the importance of storage batteries to the Class 1E system, the US Nuclear Regulatory Commission has requested Sandia National Laboratories (SNL) to evaluate the impact of aging and seismic exposure on battery capacity. Ontario Hydro has been subcontracted to carry out capacity and seismic shaker tests on naturally aged cells supplied by SNL from several US nuclear power stations (SNL contract 47-4077). The program addresses possible variations between designs produced by different manufacturers.

This report describes the results of a series of experiments carried out at the Ontario Hydro Research Laboratories on a set of ten year old C&D LCU-13 cells from the North Anna Nuclear Power Station (Virginia Electric and Power Company). The tests showed that the fragility level of the cells (ie, the level of skaking above which the cells would experience damage that reduces their capacity) was beyond the capacity of the shaker table. To determine if there was any age related deterioration of the internal components of the cells that did not manifest itself during the shaker tests, several cells were disassembled for inspection and metallurgical examination. The results indicate that this batch of cells was in good condition.

This report summarizes the tests and results of this batch of cells. A more detailed discussion of the tests and results is contained in reports C84-107-P (battery condition and performance)/1/ and B84-419-P (seismic test results)/2/.

The tests described here were part of a larger program of testing of aged cells. Other cell types tested to date have included Gould FKR (Pickering NGS)/3,4,5/, Gould NCX2250 (J.A. Fitzpatrick NPS)/6/, Exide EMP-13 (Shippingport NPS)/7/ and Exide FHC-19 (Calvert Cliffs NPS)/8/.

2.0 TEST METHODS AND RESULTS

2.1 Initial Inspection and Conditioning

Twelve C&D LCU-13 cells were received from the North Anna plant. Once inspected for superficial damage (there was none), the cells were conditioned (charged and discharged several times to stabilize their condition) and tested for capacity. The electrical state of the cells prior to the seismic tests is summarized in Table 1.

2.2 Seismic Testing - Single Cells

The shaker table and instrumentation used in these experiments is described in Reference /2/. The table provides independent motion in three directions. The motion is based on a quasi-random signal, filtered to match the frequency content of a typical earthquake. The duration of each test was 30 s. The seismic test method conformed to the recommendations of IEEE Std 344-1975 and IEEE Std 501-1978.

For the first phase of the seismic testing, the cells were mounted individually on the shaker table in a stiff frame, designed to minimize relative motion between the cell jar and the table (see Figure 1). This phase was intended to investigate possible failure modes of internal components. The rig was designed to minimize the danger of jar failure and acid spill. Accelerometers were mounted on the base of the frame and on the top of one of the posts of the cell.

Each cell was subjected to a series of tests at successively higher acceleration levels. The test sequence for each cell is shown in the test log given in Table 2. In this record, the acceleration level for each test is quoted in terms of the span setting of the amplifier in the shaker control system. Because the input motion is random, it is impossible to define the relationship between span setting and acceleration exactly. The table below is approximate.

Span Setting	ZPA of Fitted IEEE 501 Spectrum (g)	Maximum Acceleration (g)
3	0.6	1.5
4	0.8	2.0
5	1.0	2.5
6	1.3	3.2
7 (machine limit)	1.5	3.8

During the seismic tests, the cells were discharged against a resistive load at a 1 h discharge rate. They were considered to have passed a seismic test if they remained above 1.75 V during and immediately after the test. The cells were shaken at progressively higher levels up to the machine limit. Each of the four cells that were tested in the single cell frame passed all of the tests. Table 2 provides a log of the test sequence, while Table 3 summarizes the results. Figures 3-14 show response spectra for the final test on each cell. There were no sudden drops in cell voltage during any of the shaker tests.

The seismic test results are presented in this report and in Reference/2/ in terms of acceleration response spectra of the table motion. To provide a convenient means of comparing the acceleration levels encountered during various tests, each tests spectrum is compared to a normalized spectrum defined in IEEE Std 501-1978/9/. The shape of this spectrum is intended to reflect the frequency content of the "typical" seismic environment for electrical equipment. The intensity of the simulated seismic motion is expressed in terms of the ZPA (zero period acceleration) which closely corresponds to the peak acceleration of the base.

2.3 Jar Fragility Test

Earlier testing (Gould NCX2250 cells from J.A. Fitzpatrick NPP/6/) had shown that cracks in the jars would propagate more readily if the cell was mounted loosely in the test frame. A single test was carried out with an LCU-13 cell loosely mounted in the frame. In this case, the cell jar had no sign of prior cracking and no damage occurred as a result of the test.

2.4 Multi Cell Rack Test

The single cell tests were designed to focus on failure modes of internal components. To examine the possible failure modes that would be encountered with normal in-plant mounting arrangements, a shaker test was carried out on a set of three cells mounted on a rack that resembled typical seismically qualified battery racks (see Figure 2). The test log and results are shown on Tables 2 and 3. Figures 15-17 show response spectra for the final test on the rack mounted cells. Again, no failures occurred.

For practical reasons, the rack that was used for these tests held only three cells. Full scale racks in generating stations are typically much longer. The present tests could be non-conservative since long strings of cells could, under violent shaking, impose large impact loads on cells at the end of the string. These tests provide no positive indication that this is a potential source of trouble. Nevertheless, we suggest that in severe seismic environments, it would be beneficial to separate cells into groups of three or so, with rigid partitions on the rack and flexible electrical connections between groups.

2.5 Post Seismic Capacity Tests and Inspection

Following the shaker table tests the cells were re-tested for electrical capacity. The results of these tests are shown on Table 1. There was some loss of discharge capacity for all cells. However, the cell capacities, as measured from the start of the seismic test series met the acceptance criterion of more than 80% rated capacity.

Following these tests, four of the cells were disassembled and inspected. It was found that the internal components were in excellent condition with very little plate growth, cracking or pitting and with only a modest amount of sediment.

3.0 CONCLUSIONS

1. The ten year old C&D LCU-13 cells that were the subject of this study were in good condition. They were all able to survive repeated strong shaking without failing. There was apparently some loss of electrical capacity due to the seismic tests, but the capacity was still above rated capacity.

2. Internal components of all of the cells that were disassembled appeared to be in good condition with little plate swelling, cracking or pitting. There was only a modest amount of sediment.

3. There were no signs of damage to the jars during any of the tests. This includes tests where a cell was free to move in the test frame (and hence would be subject to impact loads) and tests with multi-cell racks.

4.0 ACKNOWLEDGEMENTS

Test cells and funding for this project were provided by Sandia National Laboratories. This support is gratefully acknowledged. Lloyd Bonzon and Don Hente of SNL are thanked for their large contribution to the project. Within Ontario Hydro, con-

tract coordination was handled by the Electrical Design Department. We are grateful to Colin Royce and Jerry Schendel for their efforts. Much of the testing and analysis was carried out by Brian Aucoin of the Chemical Research Department and Gordon Paulson of the Mechanical Research Department. Their able work was essential to the successful outcome of the project.

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5. D.A. Black and G.D. Paulsen, "Seismic Testing of Gould Cells Removed from Pickering GS in a Rack". Ontario Hydro Research Division Report B84-39-P.

6. J.D. Tulk, D.A. Black, W.J. Janis and B.M. Kukreti, "Seismic Testing of Naturally Aged Station Battery Cells". NUREG/CR-3923 SAND 84-1737 (also issued as Ontario Hydro Research Division Report B84-211-K).

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8. J.D. Tulk, D.A. Black, W.J. Janis and B.M. Kukreti, "Seismic Testing of Naturally Aged Exide FHC-19 Station Battery Cells". Ontario Hydro Research Division Report B84-426-K.

9. IEEE Std 501-1978, "IEEE Standard, Seismic Testing of Relays". The Institute of Electrical and Electronics Engineers Inc., 1978.

TABLE 1

CELL CAPACITIES BEFORE AND AFTER SEISMIC TESTING

Cell	Time to 1.75 VPC at 3 h Rate Rate (min)			Percent of Rated Capacity at 3 h Rate		
	Pre-Seismic	Post-Seismic*	Post-Seismic Plus Seismic	Pre-Seismic	Post Seismic*	Post-Seismic Plus Seismic**
6	184	165	176	102	92	98
7	206	190	198	114	106	110
36	206	145	156	114	81	87
46	181	160	168	101	89	93
48	187	155	161	104	86	89
50	112	160	168	107	89	93
57	192	165	176	107	92	98
AVG	193	163	172	107	91	95

* Cells not recharged following seismic testing.

** Capacity during seismic test at 1 h rate converted to 3 h capacity and added to post-seismic capacity, as discussed in Report C84-107-P.

TABLE 2

TEST HISTORY - NORTH ANNA NPP - C&D BATTERIES MODEL LCU-13

CELL	DATE	TIME	RUN	SPAN	COMMENTS
7	July 24/84	1:14	1	3	
7	July 24/84	1:24	2	4	
7	July 24/84	1:25	3	5	
7	July 24/84	1:26	4	6	
7	July 24/84	1:27	5	7	Plotted
46	July 24/84	2:07	1	4	
46	July 24/84	2:27	2	4	
46	July 24/84	2:28	3	5	
46	July 24/84	2:29	4	6	
46	July 24/84	2:30	5	7	Plotted
50	July 24/84	3:00	1	4	
50	July 24/84	3:01	2	5	
50	July 24/84	3:02	3	6	
50	July 24/84	3:03	4	7	Plotted
50	July 24/84	3:07	5	7	Clamps Loose
48	July 25/84	9:39	1	4	
48	July 25/84	9:41	2	5	
48	July 25/84	9:42	3	6	
48	July 25/84	9:43	4	7	Plotted
		Rack Test			
57,6,36	July 26/84	11:00	1	4	
57,6,36	July 26/84	11:03	2	5	
57,6,36	July 26/84	11:07	3	6	
57,6,36	July 26/84	11:09	4	7	Plotted

TABLE 3

TEST RESULTS

CELL NUMBER	DIRECTION	ZPA (9)	SPAN
7	X-BASE	1.29	7
7	Y-BASE	1.88	7
7	Z-BASE	1.54	7
7	X-TOP	1.56	7
7	Y-TOP	0.8	7
7	Z-TOP	1.57	7
46	X-BASE	0.98	7
46	Y-BASE	2.74	7
46	Z-BASE	1.22	7
46	X-TOP	1.22	7
46	Y-TOP	0.92	7
46	Z-TOP	1.45	7
50	X-BASE	1.22	7
50	Y-BASE	1.89	7
50	Z-BASE	1.31	7
50	X-TOP	1.42	7
50	Y-TOP	0.89	7
50	Z-TOP	1.42	7
48	X-BASE	1.31	7
48	Y-BASE	1.56	7
48	Z-BASE	1.47	7
48	X-TOP	1.31	7
48	Y-TOP	0.83	7
48	Z-TOP	1.52	7
6,57,36	X-BASE	1.10	7
6,57,36	Y-BASE	1.92	7
6,57,36	Z-BASE	1.26	7
6,57,36	X-TOP	1.53	7
6,57,36	Y-TOP	0.89	7
6,57,36	Z-TOP	1.51	7

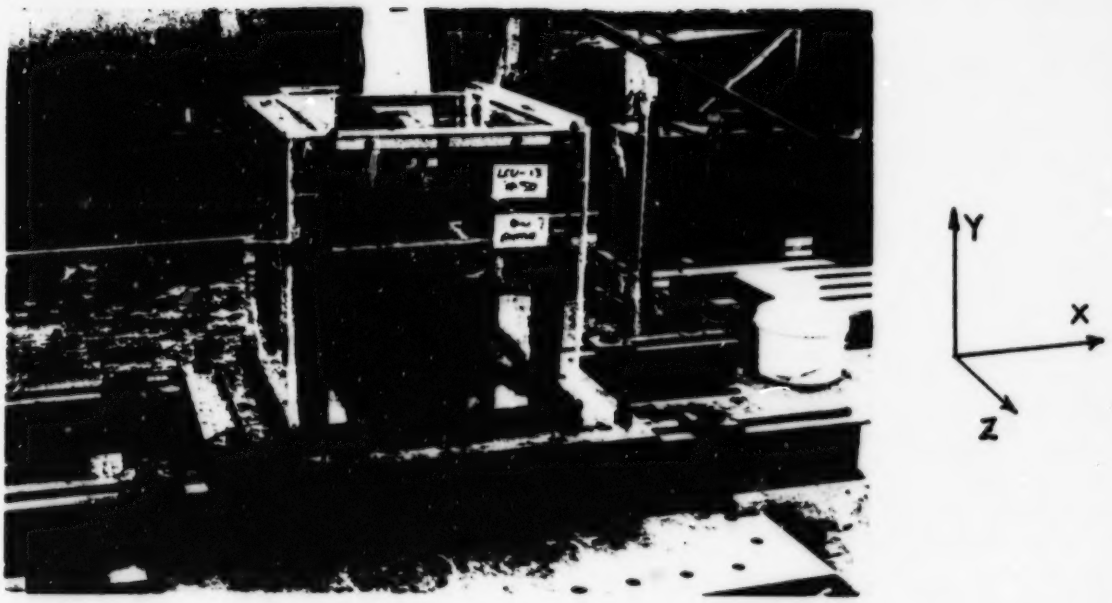


Figure 1

Typical mounting of a C&D LCU-13 cell in single-cell frame. Cell is clamped at four corners with threaded rods. Accelerometers are mounted on the base and on one of the terminal posts.

Axes of vibration are indicated.

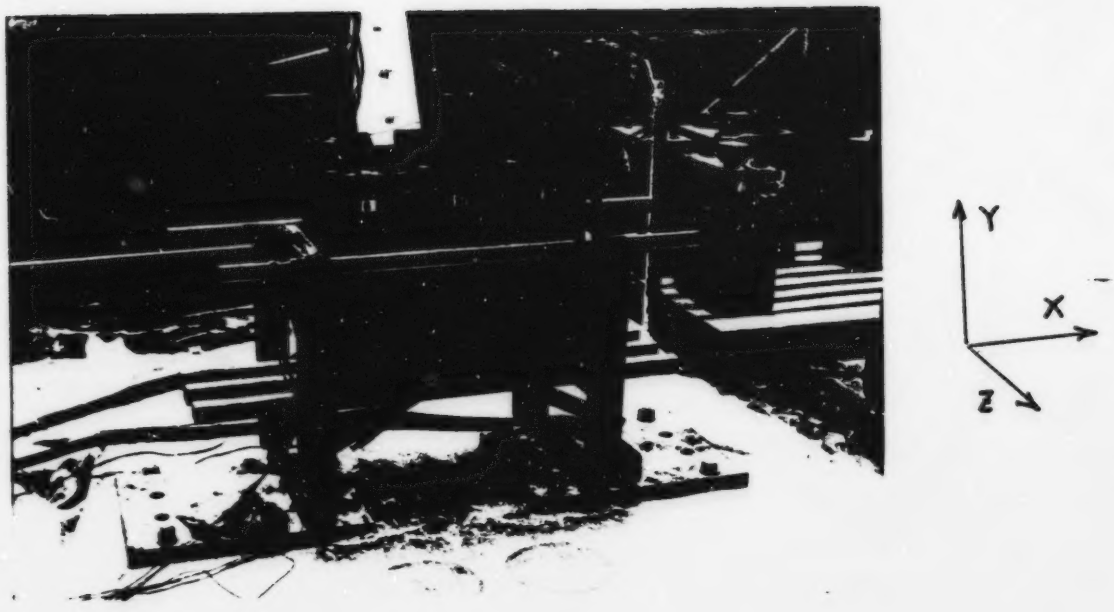
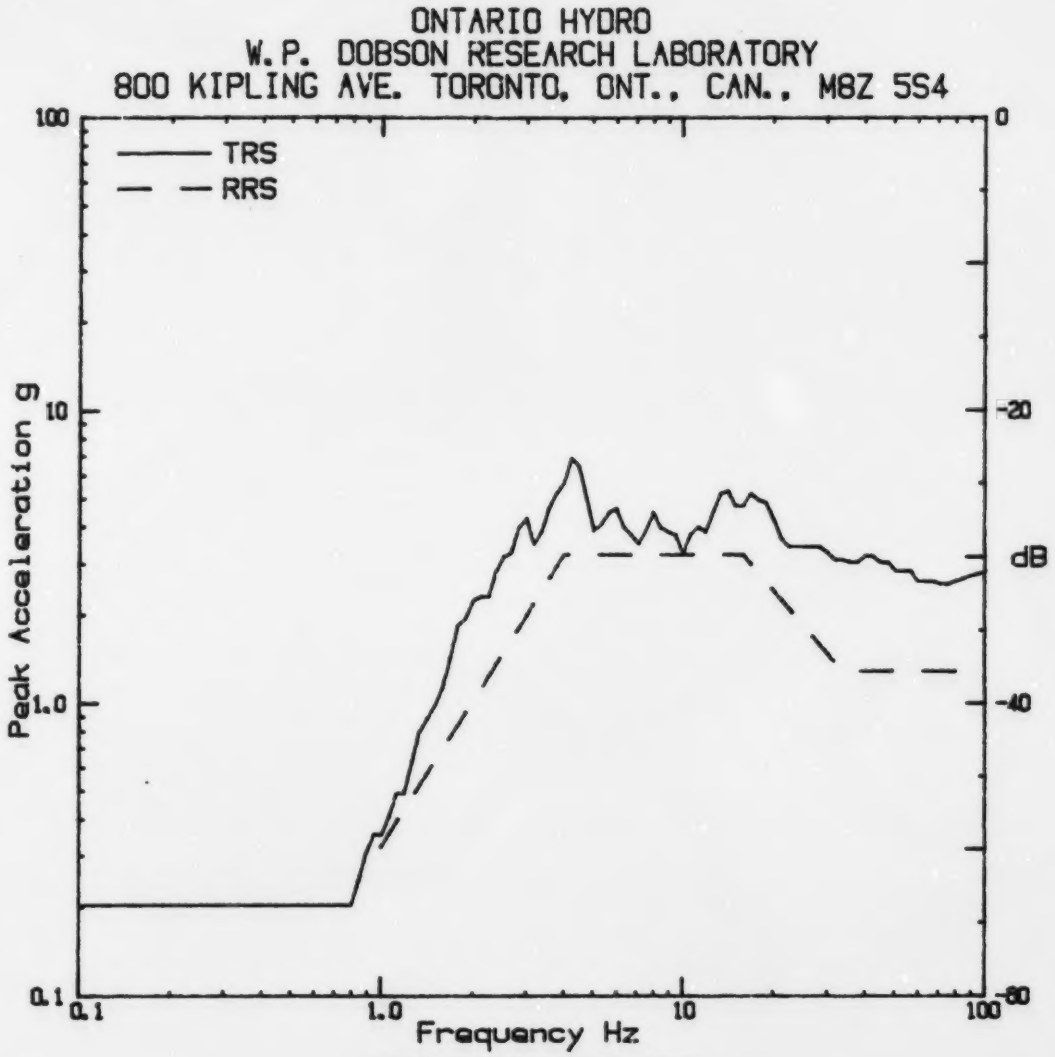


Figure 2

Mounting of C&D LCU-13 cells in multi-cell rack.

Axes of vibration are indicated.



RESPONSE SPECTRUM

FIGURE 3

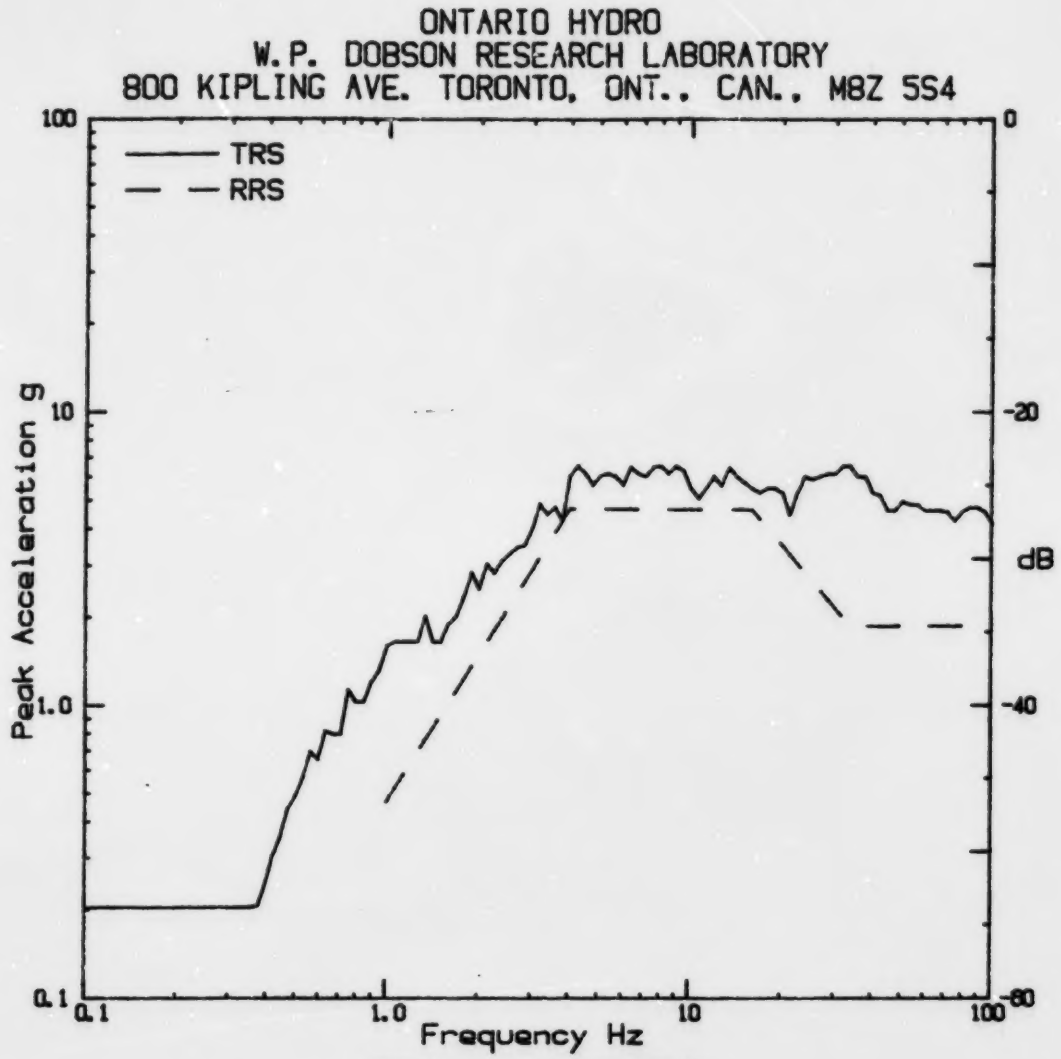
TEST ITEM
station cell, C&D Batteries, Model LCU-13, Serial 7

PARTICULARS
July 23/84, Time 1:28, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2, Graph 5224

SPECIFICATIONS
Specs IEEE 501, Conditions operating ; 3 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.29g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB49, Location base-mounting plate, Channel 1



RESPONSE SPECTRUM

FIGURE 4

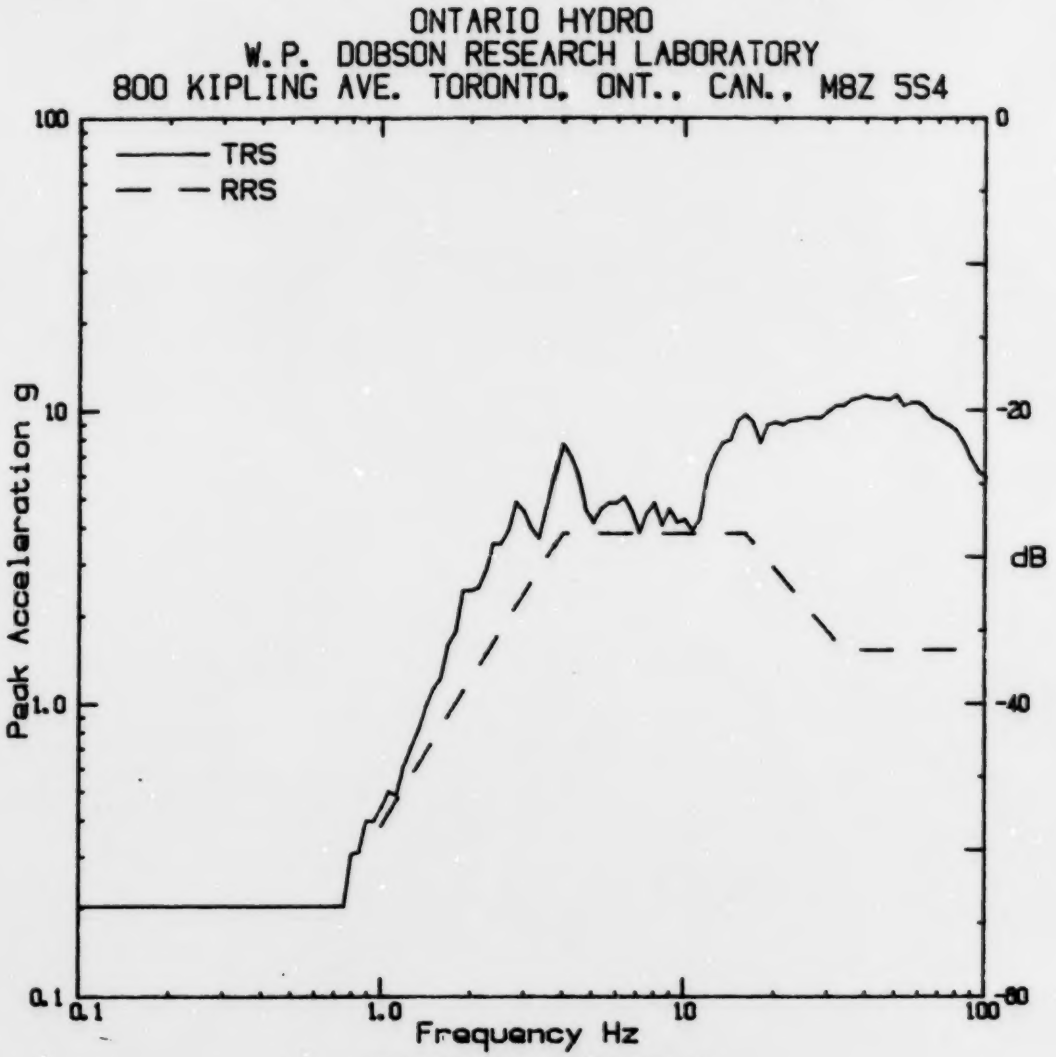
TEST ITEM
station cell, C&D Batteries, Model LCU-13, Serial 7

PARTICULARS
July 23/84. Time 1:28. Temp('C) 23. Humidity(%) 53. Press (kPa) 100.2. Graph 5225

SPECIFICATIONS
Spec IEEE 501. Conditions operating ; 1 hour rate, span 7

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.88g

ACCELEROMETER
Wilcoxon, Serial S761. Range dB49. Location base-mounting plate. Channel 2



RESPONSE SPECTRUM

FIGURE 5

TEST ITEM
station cell, C&D Batteries, Model LCU-13, Serial 7

PARTICULARS
July 23/84, Time 1:28, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2,
Graph 5228

SPECIFICATIONS
Spec IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.54g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB49, Location base-mounting plate,
Channel 3

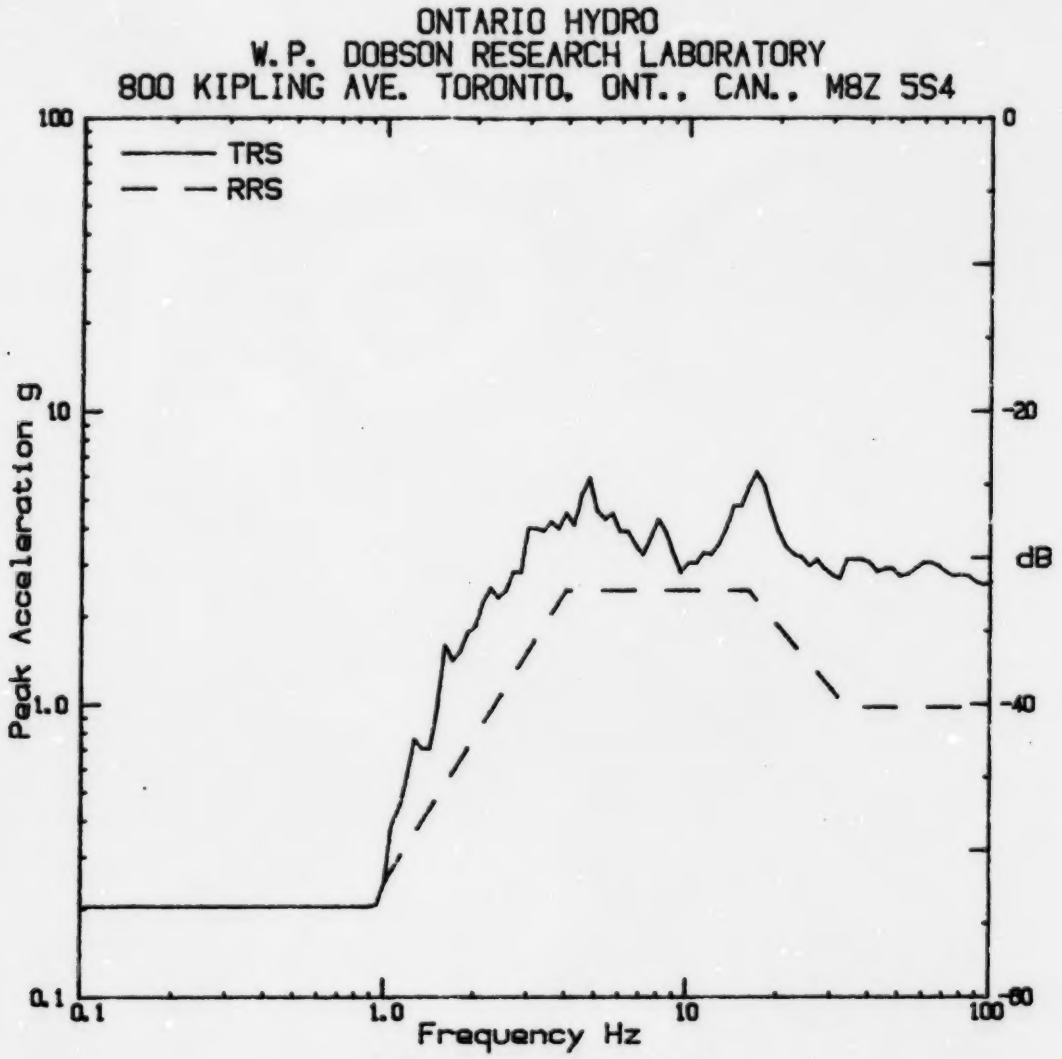


FIGURE 6

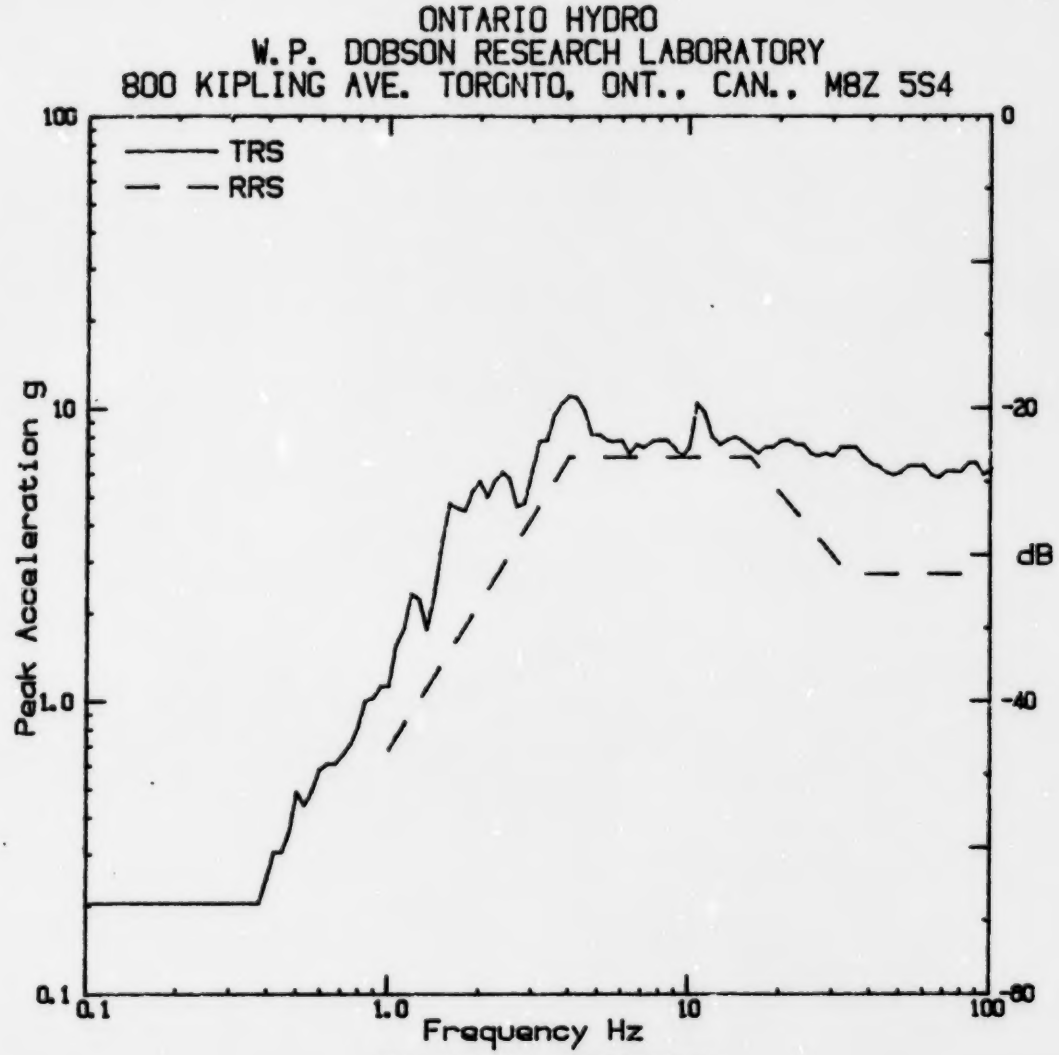
TEST ITEM
Station cells, C&D Batteries, Model LCU-13, Serial 46

PARTICULARS
July 23/84, Time 2:30, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2,
Graph 5230

SPECIFICATIONS
Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=.98g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB49, Location base-mounting plate,
Channel 1



RESPONSE SPECTRUM

FIGURE 7

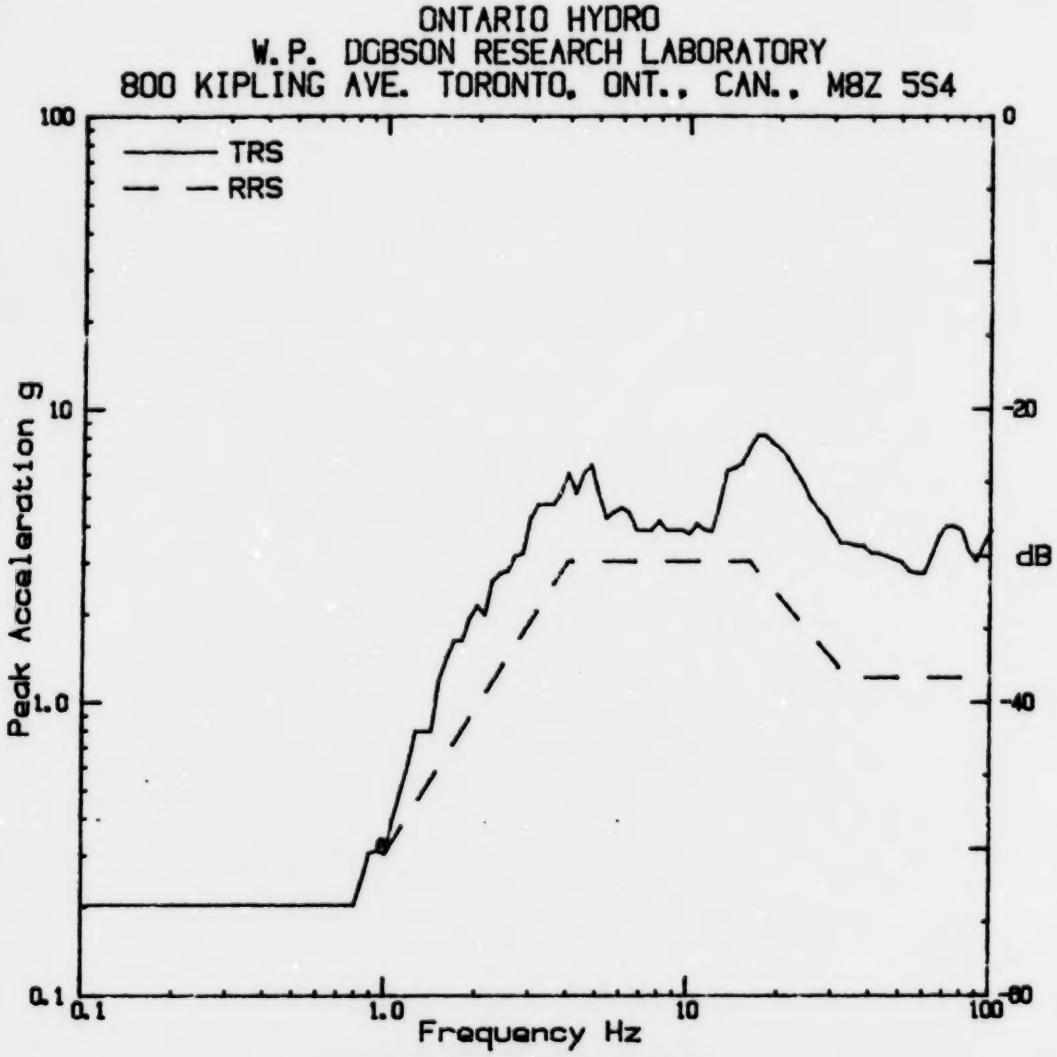
TEST ITEM
Station calls, C&D Batteries, Model LCU-13, Serial 48

PARTICULARS
July 23/84, Time 2:30, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2,
Graph 5231

SPECIFICATIONS
Spece IEEE 501, Conditions operating ; 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=2.74g

ACCELEROMETER
Wilcoxon, Serial S781, Range dB49, Location base-mounting plate,
Channel 2



RESPONSE SPECTRUM

FIGURE 8

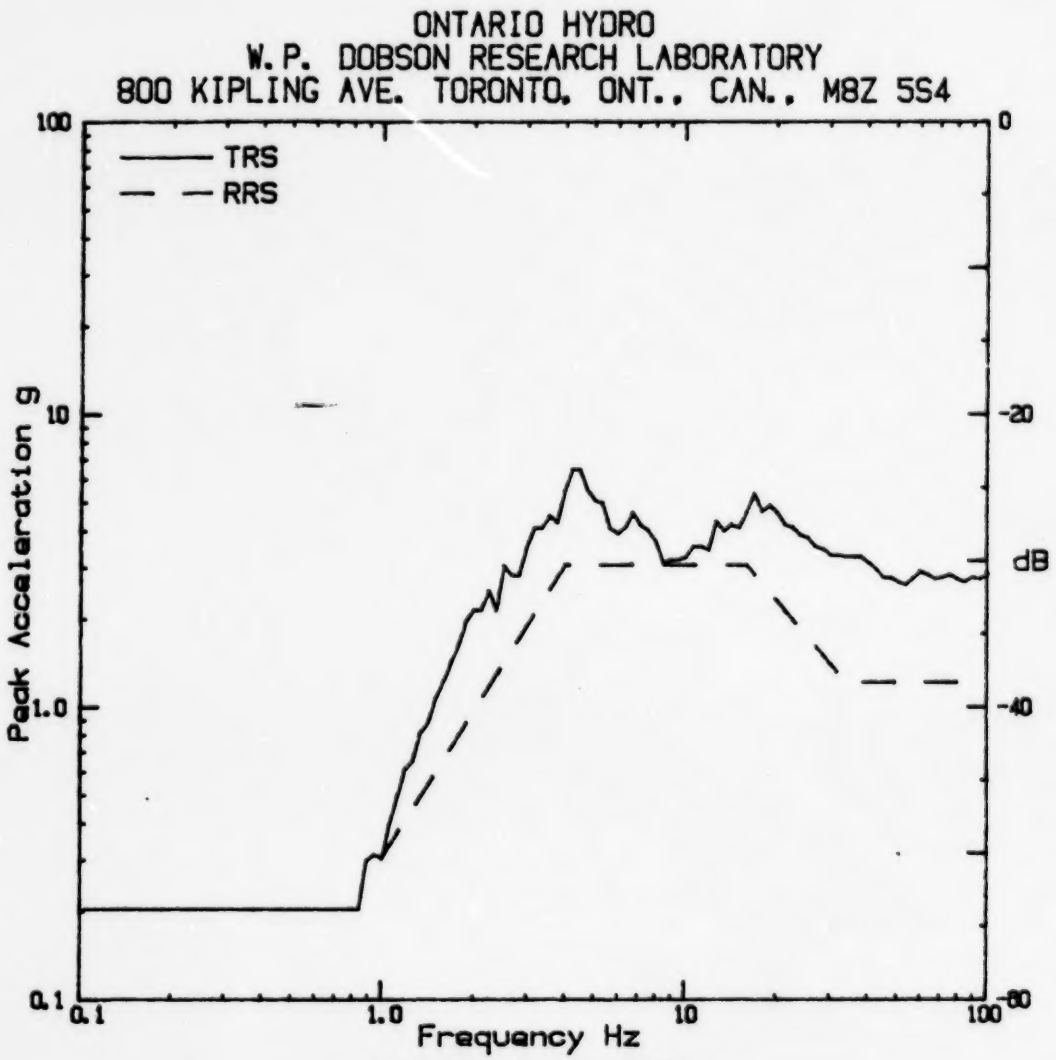
TEST ITEM
Station cells, C&D Batteries, Model LCU-13, Serial 46

PARTICULARS
July 23/84, Time 2:30, Temp(°C) 23, Humidity(%) 53, Press (kPa) 100.2,
Graph 5232

SPECIFICATIONS
Spec: IEEE 501, Conditions operating ; 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.22g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB49, Location base-mounting plate,
Channel 3



RESPONSE SPECTRUM

FIGURE 9

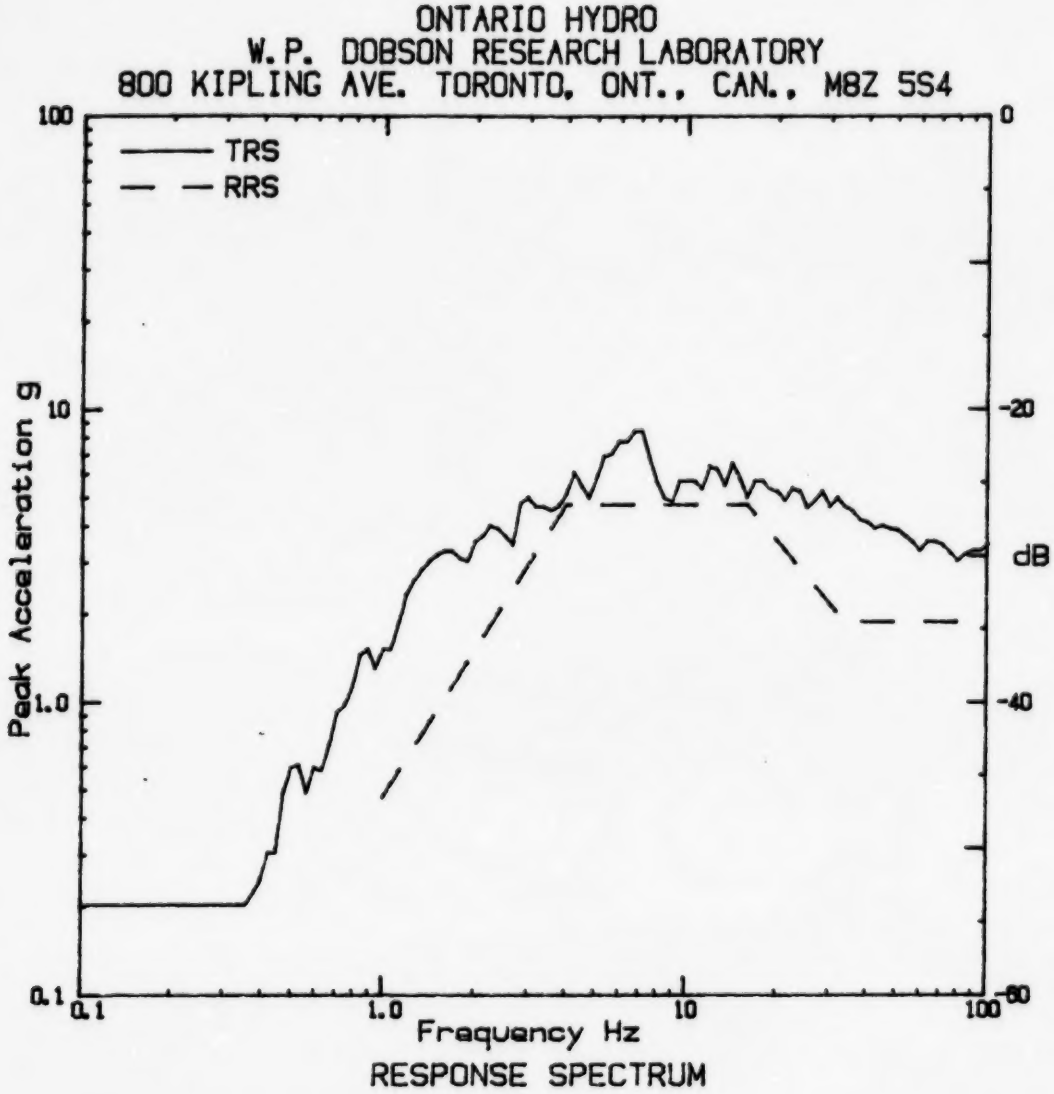
TEST ITEM
Station cells, C&D Batteries, Model LCU-13, Serial 50

PARTICULARS
July 23/84, Time 3:03, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2,
Graph 5236

SPECIFICATIONS
Spec IEEE 501, Conditions operating ; 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X.
Shaker tri-axial, ZPA=1.22g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB49, Location base-mounting plate,
Channel 1



RESPONSE SPECTRUM

FIGURE 10

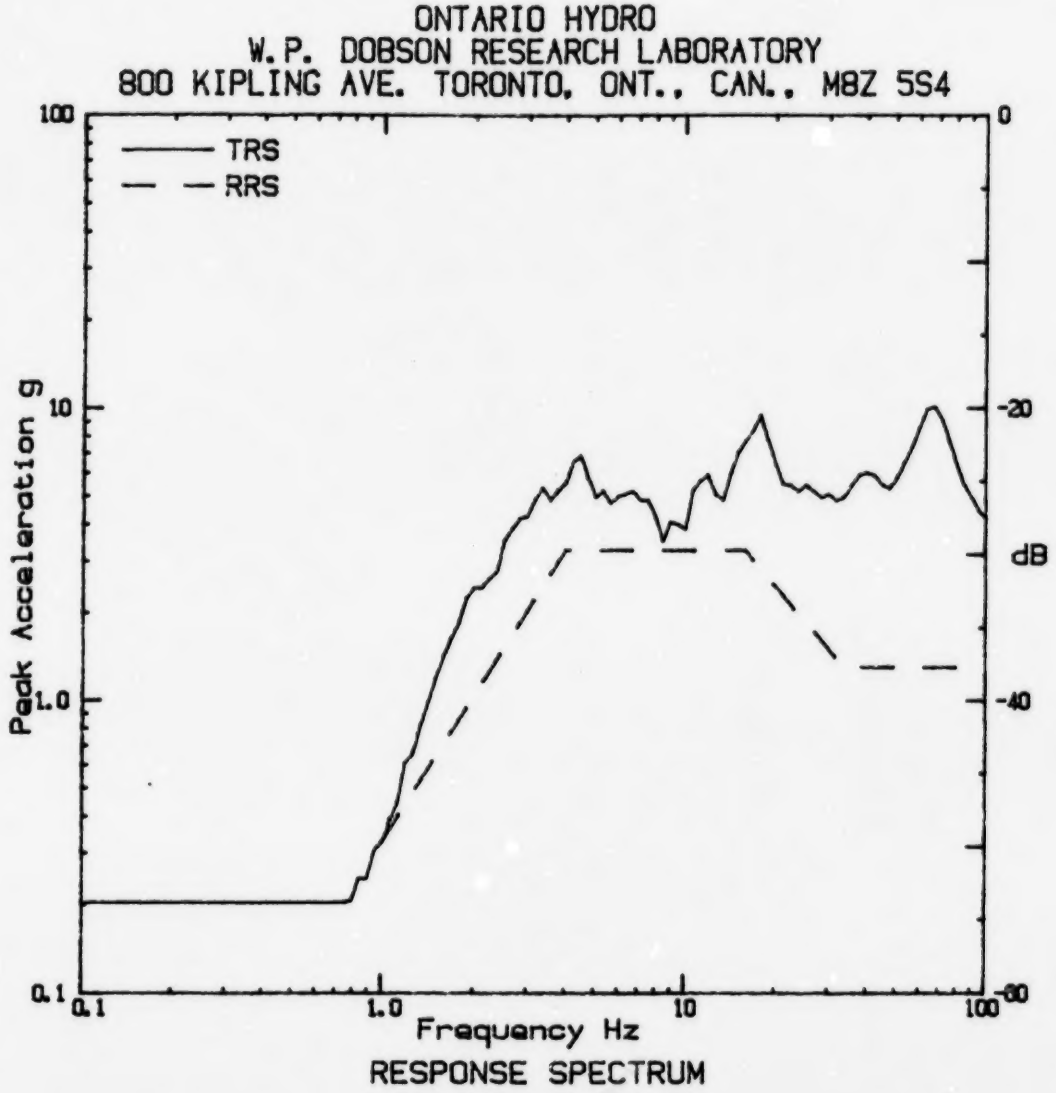
TEST ITEM
Station cells, C&D Batteries, Model LCU-13, Serial 50

PARTICULARS
Jwly 23/84, Time 3:03, Temp('C) 23, Humidity(%) 53, Press (kPa)100.2,
Graph 5237

SPECIFICATIONS
Spece IEEE 501, Conditions operating ; 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.89g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB49, Location base-mounting plate,
Channel 2



RESPONSE SPECTRUM

FIGURE 11

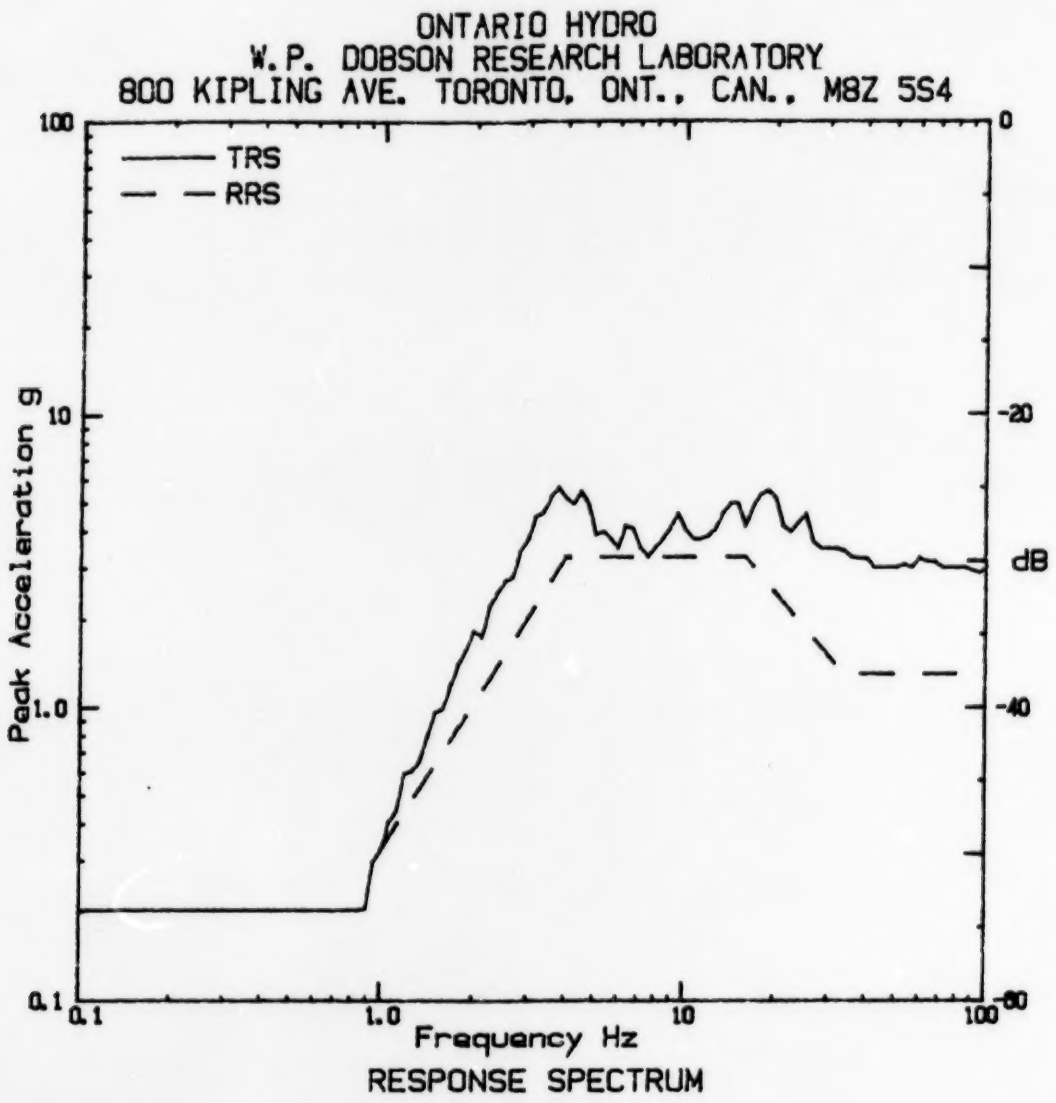
TEST ITEM
Station cells, C&D Batteries, Model LCU-13, Serial 50

PARTICULARS
July 23/84, Time 3:03, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2, Graph 5238

SPECIFICATIONS
Spec IEEE 501, Conditions operating ; 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z, Shaker tri-axial, ZPA=1.31g

ACCELEROMETER
Wilcoxon, Serial 5297, Range d849, Location base-mounting plate, Channel 3



RESPONSE SPECTRUM

FIGURE 12

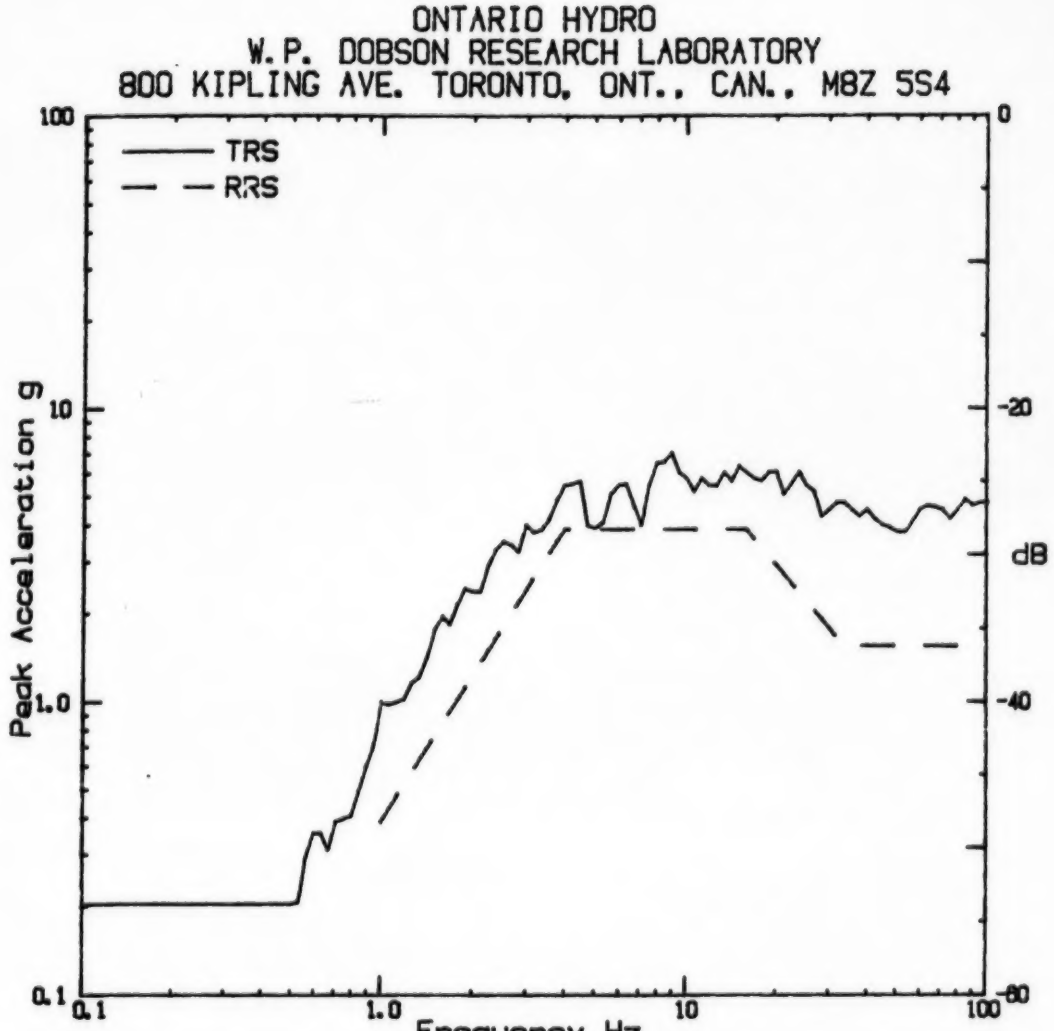
TEST ITEM
Station cells, C&D Batteries, Model LCU-13, Serial 48

PARTICULARS
July 24/84, Time 9:43, Temp('C) 23, Humidity(%) 55, Press (kPa) 100.3,
Graph 5242

SPECIFICATIONS
Specs IEEE 501, Conditions operating ; 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.31g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB49, Location base-mounting plate,
Channel 1



RESPONSE SPECTRUM

FIGURE 13

TEST ITEM
Station cells, C&D Batteries, Model LCU-13, Serial 48

PARTICULARS
July 24/84, Time 9:43, Temp('C) 23, Humidity(%) 55, Press (kPa) 100.3, Graph 5243

SPECIFICATIONS
Spec IEEE 501, Conditions operating ; 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y, Shaker tri-axial, ZPA=1.58g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB49, Location base-mounting plate, Channel 2

ONTARIO HYDRO
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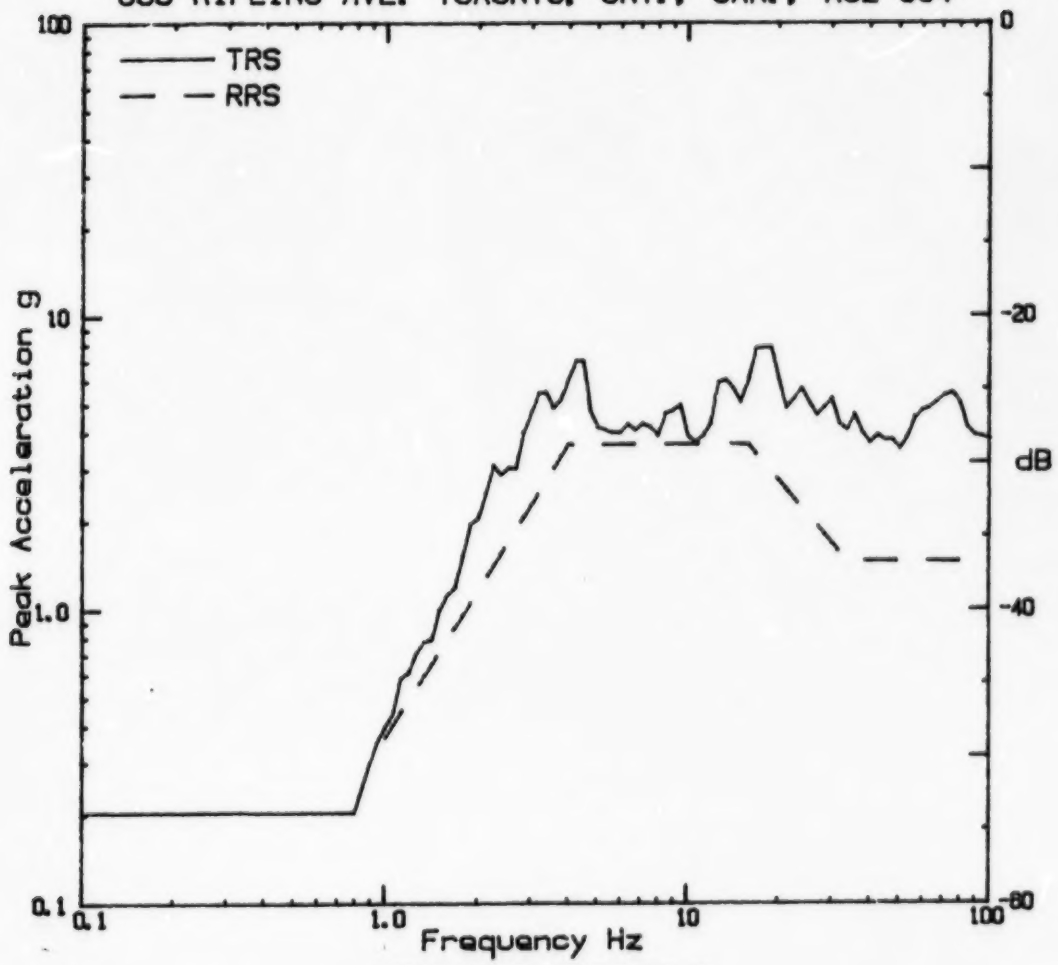


RESPONSE SPECTRUM

FIGURE 14

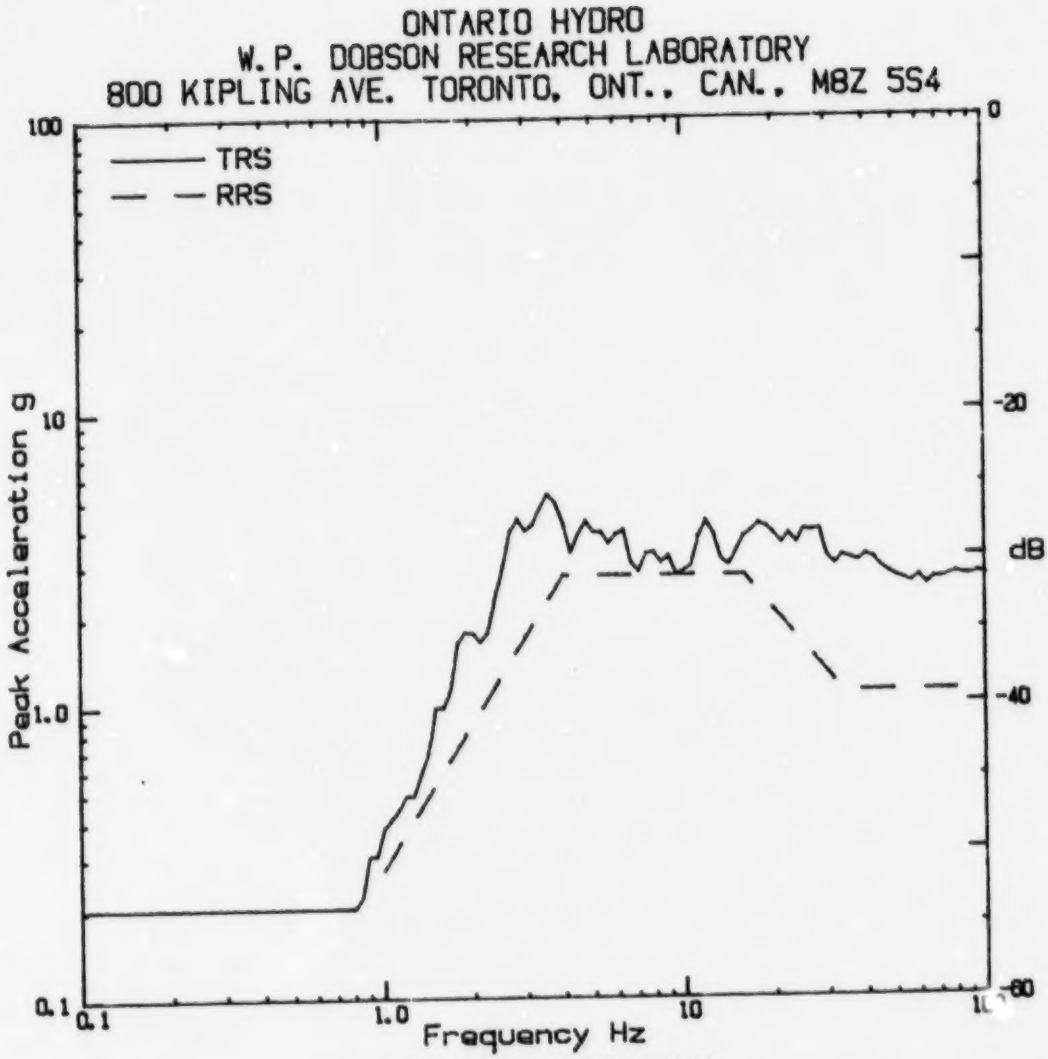
TEST ITEM
Station cells, C&D Batteries, Model LCU-13, Serial 48

PARTICULARS
July 24/84, Time 9:43, Temp('C) 23, Humidity(%) 55, Press (kPa) 100.3,
Graph 5244

SPECIFICATIONS
Spec IEEE 501, Conditions operating ; 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.47g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB49, Location base-mounting plate,
Channel 3



RESPONSE SPECTRUM

FIGURE 15

TEST ITEM
Station cells & Rack. C&D Batteries. Model LCU-13. Serial 6.57.36

PARTICULARS
July 26/84. Time 11:09. Temp('C) 23. Humidity(%) 55. Press (kPa) 100.
Graph 5254

SPECIFICATIONS
Specs IEEE 501. Conditions operating ; 1 hour rate. span 7

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.1g

ACCELEROMETER
Wilcoxon. Serial S771. Range dB49. Location base-mounting plate.
Channel 1